Guiding Questions

1. What role could comets and meteorites have played in the origin of life on Earth?
2. Have spacecraft found any evidence for life elsewhere in our solar system?
3. Do meteorites from Mars give conclusive proof that life originated there?
4. How likely is it that other civilizations exist in our Galaxy?
5. How do astronomers search for evidence of civilizations on planets orbiting other stars?
6. Will it ever be possible to see Earthlike planets orbiting other stars?
Life and the Universe

• Searching for life everywhere
• Planets, stars, galaxies, Big Bang
  – Conception of size and distance
• Stars and the origins of chemicals
• Formation of planets
• Defining astrobiology – the science
The Science of Life in the Universe

- Ancient cosmologies
- Science as a way of knowing
- Copernicus, Galileo, Kepler, Newton
- Pseudoscience and nonsense
The Nature of Life

- What is it?
- Cells
- Metabolism
- DNA
- Extremophiles
The chemical building blocks of life are found throughout space

- All life on Earth, and possibly on other worlds, depends on organic (carbon-based) molecules
- These molecules occur naturally throughout interstellar space
- The organic molecules needed for life to originate were probably brought to the young Earth by comets or meteorites
Another likely source for organic molecules is chemical reactions in the Earth’s primitive atmosphere.

Similar processes may occur on other worlds.
The Origin and Evolution of Life on Earth

- Origin of Life
- Prokaryotes
- Eukaryotes
- Oxygen in Air
- Impacts & Extinctions
- Human Evolution
Searching for Life in the Solar System

- Environmental Needs
- In the Solar System

Essential Requirements for Life

- Energy
  - Solar Light
  - Chemical Energy may be
    - Photosynthesis
    - Inorganic
    - Organic
      - Production of Pigments
      - Absorbent Layers
        - UV Radiation Protection
          - Includes, such as
            - Rocks
            - Ozone

Major Biogenic Elements
- Carbon C,
- Hydrogen H,
- Nitrogen N,
- Oxygen O,
- Phosphorus P,
- Sulfur S

Building Blocks for Life
- Diamolecules
  - Cells
    - Cellular Energy
      - to produce
        - Adenosine Triphosphate

Environmental Needs

In the Solar System
The Geological History of the Earth

- Geologic Timescale
- Plate Tectonics
- Solid Earth
- Greenhouse Effect
- Relative/Absolute Dating
Abundance of the Chemical Elements

• NOTE WELL
  – Abundance in many textbooks is plotted on a logarithmic scale
    • this allows for the different elements to actually appear on the same scale as hydrogen and helium
    • it does show relative differences among higher atomic weight elements better than linear scale
  – Abundance of elements on a linear scale is very different
Log Plot of Abundance

Logarithmic Plot of Chemical Abundance of Elements

Relative Abundance

Chemical Species

H, He, C, N, O, Ne, Mg, Si, Si, Fe
Chemical Abundance vs. Atomic Number (Logarithmic Plot)
A Linear View of Abundance

Linear Plot of Chemical Abundance

Chemical Species

Relative abundance

H
He
C
N
O
Ne
Mg
Si
Si
Fe
Another Linear View

Chemical Abundance vs. Atomic Number (Linear Plot)
Other Observations

• Radioactive dating of solar system rocks
  – Earth ~ 4 billion years
  – Moon ~4.5 billion years
  – Meteorites ~4.6 billion years
• Most orbital and rotation planes confined to ecliptic plane with counterclockwise motion
• Extensive satellite and rings around Jovians
• Planets have more of the heavier elements than the sun
## Planetary Summary

<table>
<thead>
<tr>
<th>Planet</th>
<th>Mass (Earth=1)</th>
<th>Density (g/cm³)</th>
<th>Major Constituents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mercury</td>
<td>0.06</td>
<td>5.4</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Venus</td>
<td>0.82</td>
<td>5.2</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Earth</td>
<td>1.00</td>
<td>5.5</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Mars</td>
<td>0.11</td>
<td>3.9</td>
<td>Rock, Iron</td>
</tr>
<tr>
<td>Jupiter</td>
<td>318</td>
<td>1.3</td>
<td>H, He</td>
</tr>
<tr>
<td>Saturn</td>
<td>95</td>
<td>0.7</td>
<td>H, He</td>
</tr>
<tr>
<td>Uranus</td>
<td>14</td>
<td>1.3</td>
<td>Ices, H, He</td>
</tr>
<tr>
<td>Neptune</td>
<td>17</td>
<td>1.7</td>
<td>Ices, H, He</td>
</tr>
</tbody>
</table>
Other Planet Observations

• Terrestrial planets are closer to sun
  – Mercury
  – Venus
  – Earth
  – Mars

• Jovian planets furthest from sun
  – Jupiter
  – Saturn
  – Uranus
  – Neptune
Some Conclusions

• Planets formed at same time as Sun
• Planetary and satellite/ring systems are similar to remnants of dusty disks such as that seen about stars being born (e.g. T Tauri stars)
• Planet composition dependent upon where it formed in solar system
Nebular Condensation Model

- Most remnant heat from collapse retained near center
- After sun ignites, remaining dust reaches an equilibrium temperature
- Different densities of the planets are explained by condensation temperatures
- Nebular dust temperature increases to center of nebula
Nebular Condensation Physics

- Energy absorbed per unit area from sun = energy emitted as thermal radiator
- Solar Flux = Lum (Sun) / 4 x distance$^2$
- Flux emitted = constant x $T^4$ [Stefan-Boltzmann]
- Concluding from above yields
  - $T = \text{constant} / \text{distance}^{0.5}$
<table>
<thead>
<tr>
<th>Molecule</th>
<th>Freezing Point</th>
<th>Distance from Center</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂</td>
<td>10 K</td>
<td>&gt;100 AU</td>
</tr>
<tr>
<td>H₂O</td>
<td>273 K</td>
<td>&gt;10 AU</td>
</tr>
<tr>
<td>CH₄</td>
<td>35 K</td>
<td>&gt;35 AU</td>
</tr>
<tr>
<td>NH₃</td>
<td>190 K</td>
<td>&gt;8 AU</td>
</tr>
<tr>
<td>FeSO₄</td>
<td>700 K</td>
<td>&gt;1 AU</td>
</tr>
<tr>
<td>SiO₄</td>
<td>1000 K</td>
<td>&gt;0.5 AU</td>
</tr>
</tbody>
</table>
Nebular Condensation Summary

- Solid Particles collide, stick together, sink toward center
  - Terrestrials -> rocky
  - Jovians -> rocky core + ices + light gases
- Coolest, most massive collect H and He
- More collisions -> heating and differentiating of interior
- Remnants flushed by solar wind
- Evolution of atmospheres
Mars

- Science Fiction
- Search for Life
- Martian Meteorites
- Exploration
Both of the NASA rovers that reached Mars in 2004 landed at locations that may once have been covered in water

- The unsuccessful Beagle 2 mission to Mars was to carry out a different set of biological experiments on samples taken from the interiors of rocks
- These experiments may be attempted again on a future mission
The *Viking Lander* spacecraft searched for microorganisms on the Martian surface, but found no conclusive sign of their presence.
A “Face” on Mars
Meteorites from Mars have been scrutinized for evidence of past life

- A Martian rock that came to Earth as a meteorite was examined for circumstantial evidence that microorganisms once existed on Mars
- The science community does is skeptical, and more samples are needed for additional evidence
Life on Jovian Moons

- Europa
- Titan
- Others
Europa and Mars have the potential for life to have evolved

- Besides Earth, there are two worlds in our solar system—the planet Mars and Jupiter’s moon Europa—may have had the right conditions for the origin of life
- Mars once had liquid water on its surface, though it has none today
- Life may have originated on Mars during the liquid water era
- Europa may have extensive liquid water beneath its icy surface
- A future mission to search for the presence of life on Europa has been cancelled
The Nature and Evolution of Habitability

- Habitability Zone
  - Past, Present, Future
The Search for Habitable Worlds

- Planet Formation
- Extrasolar Planets
  - Detection
- Earth-like Planets?
Infrared telescopes in space will soon begin searching for Earthlike planets

• A new generation of orbiting telescopes may be able to detect terrestrial planets around nearby stars
• If such planets are found, their infrared spectra may reveal the presence or absence of life
The Search for Extraterrestrial Intelligence

• SETI
• Drake Equation

\[ N_\text{o} = N \ast \times f_p \times n_p \times f_l \times f_i \times f_c \times L \]

The Drake Equation

\[ N_T = R_* f_p n_e f_l f_i f_c t_1 \]

- \( N_T \) - number of communicative civilizations
- \( R_* \) - mean rate at which suitable stars are born, 1-10/y
- \( f_p \) - fraction of stars with planetary systems, 0.1-0.5
- \( n_e \) - number of Earth-like worlds per planetary system, 1-3
- \( f_l \) - fraction of those Earths where life develops, 0.1-1
- \( f_i \) - fraction of those on which intelligence develops, 0.01-1
- \( f_c \) - fraction of intelligent beings who develop technology, 0.1-1
- \( t_i \) - lifetime of a civilization with ability to communicate, \( 10^3 - 10^6 \)
The Drake equation helps scientists estimate how many civilizations may inhabit our Galaxy.

\[ N = R_\ast f_p n_c f_l f_i f_c L \]

- \( N \) = number of technologically advanced civilizations in the Galaxy whose messages we might be able to detect
- \( R_\ast \) = the rate at which solar-type stars form in the Galaxy
- \( f_p \) = the fraction of stars that have planets
- \( n_c \) = the number of planets per solar system that are Earthlike (that is, suitable for life)
- \( f_l \) = the fraction of those Earthlike planets on which life actually arises
- \( f_i \) = the fraction of those life-forms that evolve into intelligent species
- \( f_c \) = the fraction of those species that develop adequate technology and then choose to send messages out into space
- \( L \) = the lifetime of a technologically advanced civilization
Interstellar Travel

• How realistic?
  – Engineering
  – Limited by c

• Relativity and time dilation
• Wormholes and hyperspace?
The Fermi Paradox

- Where are the aliens?
- Galactic colonization
- Resolving the paradox
Contact – Implications of the Search and Discovery

• Can we make contact
  – Which kind \(1^{st}, 2^{nd}, 3^{rd}\)
• Contact implications
Radio searches for alien civilizations are under way

- No signs of intelligent life have yet been detected, but searches continue and make increasing use of sophisticated techniques.
- The so-called water hole is a range of radio frequencies in which there is little noise and little absorption by the Earth’s atmosphere.
- Some scientists suggest that this noise-free region would be well suited for interstellar communication.
If an alien civilization were someday to find this message, which of the features on the plaque do you think would be easily understandable to them?
Universe in a Nutshell

- The universe is unimaginably large, and alive.
- You, me, we are not at the center of the universe.
- The way to know the universe is through science.

» Dr. Harold Geller

See you around the universe.